CLAIMS

What is claimed is:

1. A fiber-reinforced composite spring comprising:

a spring wire comprising

a core that includes a plurality of fiber tows twisted about a longitudinal axis to create a contoured core surface; and

an outer layer of resin that is substantially devoid of said fiber tows, wherein

said outer layer has a thickness that varies along the longitudinal axis to form a generally uniform outer surface about the core.

2. The spring of claim 1, wherein the core is disposed within the spring wire at a generally central location.

3. The spring of claim 1, wherein said spring has a predictable rate of deformation when subjected to a load.

4. The spring of claim 1, wherein said spring wire has a generally cylindrical shape.

5. The spring of claim 4, wherein the core is generally concentric with the generally uniform outer surface such that the core is located at a substantially constant radial distance from the generally uniform outer surface for a cross-section of the spring wire taken at a point along the longitudinal axis.

6. The spring of claim 1, wherein said spring has a generally rectangular cross-section.

7. The spring of claim 6, wherein the core has a central axis that is generally coaxial with a central axis of the spring wire such that the central axis of the core is located at an approximately equal radial distance from opposing planar surfaces of the rectangular cross section of the generally uniform outer surface.

8. The spring of claim 1, wherein said fiber tows are natural fibers selected from the group consisting of jute and rayon fibers.

9. The spring of claim 1, wherein said fiber tows are synthetic fibers selected from the group consisting of glass, carbon, boron, boron, silicon carbide, aluminum oxide, quartz, alumina-silica, alumina-boria-silica, zerconia-silica, and fused silica fibers.

10. The spring of claim 1, wherein said resin is a thermoplastic resin.

11. The spring of claim 1, wherein said resin is a thermosetting resin selected from the group consisting of epoxy, bis-maleimide, polyimide, polyester, vinyl ester resins, polyether, ether ketone, polyphenylene sulfide, polyetherimide, and polyamide imide resins.

12. A fiber-reinforced composite spring formed by a process comprising the steps of:

impregnating a plurality of fiber tows with a resin;

encasing at least a portion of said core within a cavity having desired interior dimensions;

controlling a thickness of an outer layer formed by removing a portion of said resin from said impregnated fiber tows by twisting said core within the cavity to form a spring wire; and

shaping said spring wire to form a spring.

13. The spring of claim 12, wherein said step of encasing at least a portion of said core within said cavity comprises the steps of:

providing a generally planar sheet of flexible shroud material;

placing said core in contact with said sheet of shroud material;

wrapping said sheet of shroud material around said core; and

securing a first portion of said sheet of shroud material to a second portion of said sheet of shroud material to form said cavity around the core.

14. The spring of claim 12, wherein said step of impregnating said plurality of fiber tows with said resin comprises the step of:

impregnating said plurality of fiber tows with a thermoplastic resin.

15. The spring of claim 14, wherein the step of encasing at least a portion of said core within said cavity comprises the steps of:

at least partially solidifying said thermoplastic resin to minimize smearing of said resin while encasing said core;

inserting said core and said at least partially solidified thermoplastic resin into said cavity; and

exposing said thermoplastic resin within said cavity to a suitable source of energy for liquefying said at least partially solidified thermoplastic resin within said cavity.

16. The spring of claim 15, wherein said cavity is an interior passage defined by a shroud of flexible material that is to encase said spring wire.

17. The spring of claim 12, wherein said process further comprises the steps of:

at least partially solidifying said resin in the spring shape within said cavity; and

removing said spring wire from said cavity.

18. The spring of claim 17, wherein said resin is a thermosetting resin.

19. The spring of claim 18, wherein said step of at least partially solidifying said resin within said cavity includes the steps of:

wrapping said spring wire around a mandrel; and

at least initiating crosslinking of the thermosetting resin.

20. The spring of claim 12, wherein the step of shaping said spring wire to form said spring comprises wrapping said spring wire encased within said cavity around a mandrel.

21. A method for forming a fiber-reinforced composite spring, the method comprising the steps of:

forming a spring wire according to a method comprising the steps of

impregnating a plurality of fiber tows with a resin to form a core;

encasing at least a portion of said core within a cavity having suitable interior dimensions; and

forming an outer layer of resin having a variable thickness along a longitudinal axis to form a generally uniform outer surface by twisting said core within said cavity to remove a portion of said resin from said core; and

shaping said spring wire into a spring.

22. The method for forming a spring of claim 21, wherein the step of impregnating a plurality of fiber tows with a resin includes pultrusion.

23. The method for forming a spring of claim 21, wherein said resin for impregnating said plurality of fiber tows is a thermoplastic resin.

24. The method for forming a spring of claim 23, wherein the step of encasing at least a portion of said core within a cavity comprises the steps of:

at least partially solidifying said thermoplastic resin to minimize smearing of said resin while encasing said core;

inserting said core and said at least partially solidified thermoplastic resin into said cavity; and

exposing said at least partially solidified thermoplastic resin to a suitable source of energy for liquefying said at least partially solidified thermoplastic resin within said cavity.

25. The method for forming a fiber-reinforced spring of claim 21, wherein the cavity is defined by a flexible shroud having a cross-sectional shape selected from the group consisting of circular, rectangular, oblong, elliptical and triangular.

26. A method for forming a fiber-reinforced composite spring, the method comprising the steps of:

forming a spring wire according to a method comprising the steps of:

impregnating a core comprising a plurality of fiber tows with a resin;

encasing at least a portion of said core within a flexible shroud having suitable interior dimensions;

forming an outer layer of resin with a generally uniform outer surface; and

controlling a thickness of said outer layer by twisting said core of fiber tows within the shroud to remove a desired amount of resin from the core to form said generally uniform outer surface; and

shaping the spring wire into a spring.

28. A fiber-reinforced composite spring comprising:

a spring wire comprising

a core that includes a plurality of fiber tows twisted about a longitudinal axis to create a contoured core surface; and

an outer layer of resin having a generally uniform outer surface, wherein

shearing stress on said composite spring resulting from an applied load is generally constant along said longitudinal axis of said spring wire.

29. The spring according to claim 28, wherein said generally constant shearing stress along said longitudinal axis of said spring wire is inversely proportional to a diameter of said spring wire to the third power, and is given by the equation:

$$\tau = K_s \frac{16PR}{\pi D^3}$$

wherein Ks is 1+0.3075(D/R); P is a magnitude of a load imparted on said spring; R is an average coil radius of said spring; and D is a diameter of said spring wire.

30. The spring according to claim 28, wherein said spring wire is generally cylindrical, having a substantially constant diameter.

31. The spring according to claim 28, wherein said spring has a predictable deformation when subjected to a compressive load, said deformation being predictable from the equation:

$$\delta = \frac{64PR^3N_c}{GD^4}$$

wherein P is a magnitude of a compressive load imparted on said spring; R is an average coil radius of said spring; Nc is a number of active coils in said spring; G is a modulus of rigidity; and D is a diameter of said spring wire.